The Digitalization of Manufacturing: A Case Study

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Abstract— The digitalization of manufacturing, also known as Industry 4.0, is the fourth industrial revolution that is being substantiated by connecting cyber-physical systems to databases stored via cloud computing, enabling data acquisition in real time by management programs of the productive system. This research presents a case study of the digitalization of a manufacturing didactic cell located at IFSP-Federal Institute of São Paulo, Brazil. This study has two contributions. The first contribution categorizes the digitalization technologies of manufacturing into two parts: (i) human-machine interface and (ii) connectivity. The human-machine interface included the implementation of a new programmable logic controller that can enable data acquisition through a Supervisory Control and Data Acquisition (SCADA) system. The connectivity enables information storage that is intrinsic to the production process in cloud computing. The manufacturing cell resulted in greater connectivity and a significant improvement in the storage of information in the production process that provided remote access through electronic devices connected to the internet. This research modernized a manufacturing didactic cell that previously followed the ISA-95 model (Industry 3.0) to the technologies and trends of Industry 4.0.

Keywords— Connectivity, internet of things, cloud computing, Industry 4.0.

I. INTRODUCTION

A new industrial revolution, Industry 4.0, is being conceptualized and is changing production automation. This new concept proposes to integrate information and automation technologies, creating an intelligent network of products and services called the internet of things (IoT). The main aspect of these concepts is high connectivity between all hierarchical levels of the automation pyramid (Figure 1). With device updates and new concepts in the industrial automation area, technical standards have been updated and others are being developed to organize and standardize this new industrial scenario [1-4]. Figure 1 shows the automation pyramid according to ISA-95.

Cloud computing has recently been introduced to industrial automation because it presents itself as a virtual infrastructure that allows the use of software systems, platforms and services without the need for a physical server. According to Shahzad et al. [3], some companies have implemented a cloud infrastructure to solve problems such as access to data, the costs of software updates, limited storage, and backup recovery. According to Xu [5], in collaborative environments, the IoT and cloud are identified as main trends in business technology that will reshape current companies. Another important aspect

added to the cloud, is the provision of computing services on demand with high reliability, scalability, and the ability to be in a distributed environment [6].

Fig. 1. Automation pyramid according ISA-95 [4].

This research intends to implement the digitalization of a manufacturing didactic cell located at the São Paulo

campus of the Federal Institute of São Paulo (IFSP). The previous manufacturing cell was automated following the ISA-95 model (Industry 3.0), which presents some issues when compared to a manufacturing cell inserted in the context of Industry 4.0. The main problems are the (i) human-machine interface that lacks communication between the Supervisory Control and Data Acquisition (SCADA) supervision system and enterprise system, and the (ii) connectivity which prevents remote access of systems stored in the cloud computing via the internet.

This research occurred over two stages, the first regarding the automation technology and the second with the information technology. From the perspective of the automation technology, a new programmable logic controller, industrial network (Profinet) and a data acquisition SCADA supervision system were implemented. Regarding the information technology, a service was implemented to store some information from the manufacturing cell process in the cloud computing and an IoT application for remote access.

This paper is organized as follows: Section 1 is a general introduction of the topic. Section 2 is a brief description of the ISA-95 reference model, RAMI 4.0 reference model, Industry 4.0, cloud computing, and SCADA system. Section 3 presents the testing procedure, materials and methods, design architecture for programmable logic controller (PLC), SCADA and cloud computing, while Section 4 provides the results and conclusion.

II. THEORETICAL BACKGROUND

A. Reference Model ISA-95

The ANSI/ISA-95 model was developed in the USA and has served for manufacturing companies as a standard reference model (Industry 3.0) and for the organization of production and automation activities, including integration, terminologies and process models. The ISA-95 model does not define how the automation system should be developed, but rather the terminologies, functional requirements and information that must be used to guarantee the transparent and flexible interface between the levels of control and manufacturing management. The ISA-95 reference model is usually represented by a automation pyramid (Figure 1) of the hierarchy levels of automation systems. According to Schweichhart [4], the main characteristics of the model are: (i) hardware-based structure; (ii) functions are bound to hardware; (iii) hierarchy-based communication, and (iv) product is isolate.

The ANSI/ISA-95 standard creates a model for connecting and exchanging data between business systems (Enterprise Resource Planning, ERP) and plant operating systems (Manufacturing Execution System, MES). This connection is called Business to Management (B2M). This standard segments the hierarchical levels of the automation pyramid: Levels 1 and 2 are inherent to the control and automation of the factory floor; Level 3 corresponds to the management of the manufacturing operations; Level 4 is related to business planning and logistics and Level 5 is decision-making systems.

B. Reference Model RAMI 4.0

The traditional ISA-95 standard is oriented to a hierarchical model. The RAMI 4.0 reference model (Industry 4.0) consists of three distinct axes [4]: (i) hierarchy of levels, axis 1; (ii) product life cycle, axis 2; (iii) organizational architecture, axis 3. Figure 2 illustrates the architecture of the RAMI 4.0 reference model for Industry 4.0.
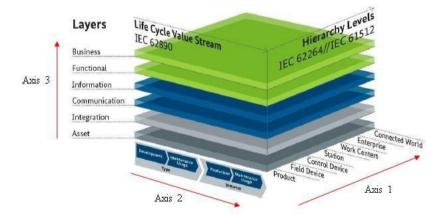

Fig. 2. Architecture of the RAMI 4.0 reference mode l [4].

Axis 1 shows the hierarchical levels of the factory (field device, control device, station, work centers and enterprise). Axis 2 shows the product life cycle (development, construction, computer simulation, prototype, product, and data). Axis 3 shows the organizational architecture and the connection between the physical world and digital world (business, functional, information, communication, integration and asset). One of the differences between the RAMI 4.0 model and ISA-95 model is that all hierarchy levels (Axis 1) can communicate with each other without a defined sequence.

C. Industry 4.0

According to Da Costa *et al*. [6], the impact of Industry 4.0 goes beyond simple digitalization, to a more complex form of innovation based on the combination of multiple technologies that will force companies to rethink how they manage their business and processes, how they position themselves in the value chain, how they think about developing new products and introducing them to the market, thereby adjusting their marketing and distribution actions. The pillars of Industry 4.0 form a set of nine enabling technologies and trends: (i) Autonomous robots; (ii) Digital Twin/Simulation; (iii) Horizontal/Vertical Software Integration; (iv) Industrial IoT; (v) Cyber Security; (vi); Cloud Computing; (vii) Additive Manufacturing; (viii) Augmented Reality, and (ix) Big Data and Analytics, as shown in Figure 3 [7].
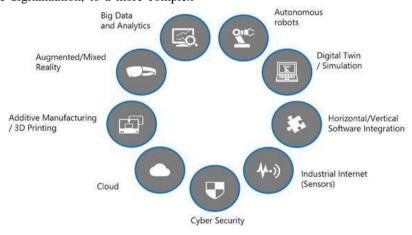

Fig. 3. The 9 Pillars of Industry 4.0 [7].

D. Cloud Computing

Cloud computing consists of storing data on virtual servers. It has the advantage of being able to access data remotely, from anywhere in the world, at any time. Another advantage is that it does not require the installation of large programs on physical hard drives [8]. According to Drath et al. [9], data can be stored and processed in the cloud, such as documents can be allocated and 3D models can be created. With the considerable increase in data flow in cloud computing, complex algorithms need to be developed to organize and make this information intelligent. The analysis of data stored in cloud computing is defined as big data [9]. Through this new scenario, new services can be implemented, connecting physical objects/users to customize services, as shown in Figure 4.

E. SCADA System

The SCADA supervision system is used for automation systems that have a high flow of information and require the use of a database. SCADA is a system made up of specific hardware and software that supervises and controls a production process of an integrated manufacturing cell [10]. In the architecture of the ISA-95 model, the SCADA system is inserted at Level 2 and is responsible for supervising the production system. For communication between the various devices with the SCADA system, the following industrial networks are used: Ethernet TCP/IP, Fieldbus, Profibus, Modbus, Profinet, AS-I, and CAN.
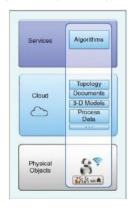

Fig. 4. Cloud computing [4].

Unlike the ISA-95 Standard, with the insertion of Industry 4.0 concepts, SCADA supervisors are integrated with systems stored in cloud computing. For users, the main benefit of this integration is in reducing costs and decreasing configuration time [11]. With the use of cloud computing in industrial areas, SCADA systems do not need to have a physical server, thus being able to virtually store data. The advantage is that several devices from the physical world can be included, generating a service-based infrastructure [12]. The resources of cloud computing are acquired on demand, at a lower cost of ownership than systems proposed by the ISA-95 model that require hardware with advanced configurations and software with high costs. With the implementation of a service-oriented architecture (SOA), cloud computing can meet industrial requirements, as these services support cooperation, offer agility and operate in a heterogeneous environment, as shown in Figure 5 [13], [14].
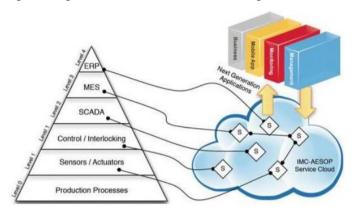

Fig. 5. SCADA based on SOA architecture [13].

III. TESTING PROCEDURE

F. Materials and Methods

This work focuses on the digitalization of a manufacturing didactic cell, located in the Laboratory of Automation and Control of the Federal Institute of São Paulo (IFSP). Figure 6 shows the manufacturing didactic cell (Model DLB CIM B, manufactured by De Lorenzo).

Fig. 6. Manufacturing didactic cell.

The focus of the digitalization was the application of the SOA and cloud technologies. The SOA-based industrial solution was implemented with the following elements: a PLC, SCADA database, and cloud service integration. These components represent services that can interact with each other. The services increased the functionality and interoperability between the factory floor with systems stored in cloud computing. An architecture for SCADA and service-oriented MES systems was created. This digitalization supports horizontal and vertical connections, such as communication between enterprise systems, plant-floor devices or controllers. This communication is an important part of Industry 4.0 for horizontal/vertical software integration, industrial IoT, cloud computing and big data. Figure 7 shows the architecture proposed for digitalization of the manufacturing didactic cell.
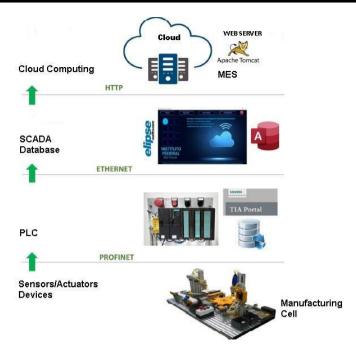
Fig. 7. Architecture proposed for digitalization of the manufacturing didactic cell.

G. Design Architecture for PLC

The architecture was based on the PLC S7-317F 2PN/DP model and on the TIA Portal software (version 15) from Siemens (Fig. 8). PLC programming was performed using Grafcet language, following the IEC 60848 standard. The Grafcet diagram was used as a system modeling tool, helping to define a representation of the manufacturing didactic cell behavior. The PLC includes the control logic and the programming focused on data acquisition, alarms and remote control. Sensors, actuators and field devices communicate with the PLC via the Profinet network. A database was developed on the PLC to store and send data to the SCADA system. In this database, the variables that interact with the SCADA system were created.

Fig. 8. Architecture proposed for PLC.

H. Design Architecture for SCADA

The SCADA system is responsible for the following functions: alarms, control, data management, Human-Machine Interaction (HMI), life cycle management, safety and process monitoring, resource management, scheduling and performance analysis. The architecture for the SCADA supervision system is based on the E3 Studio software (version 5.0.432) from Elipse. The Ethernet network (TCP/IP protocol) was used to communicate between the PLC and SCADA database.

The SCADA system (Fig. 9) acts as an interface between the manufacturing cell (physical system) and the database in cloud computing (virtual system). Another important aspect obtained as a result of the implementation of the SCADA system, was the traceability of the production system. The SCADA database has scalability that inserts a line at each part production event, stating the date and time of production, the operating condition of the cell, which operator was operating the cell and the final result of the production piece.

Fig. 9. The front panel of SCADA system.

I. Design Architecture for Cloud Computing

The IoT supports interconnection between the SCADA database and cloud computing. The Cloud hosts the representation of the environment where the services are hosted. The application server used Apache Tomcat software, an open source web server that developed by the Apache software foundation. After configuration in Tomcat, the system was prepared to function as a web server. At http://localhost:9966/manager, parameterizations were made so that the system could be transferred from a local database to a virtual database. This procedure performed the acquisition of the information from the local SCADA database every 18 seconds, updating the database using cloud computing. This cloud is private, the data stored is scalable and the data can be accessed at http://localhost:9966/IFSP.

Services with SCADA, HMI and MES functionality were implemented. With this implementation, some services were made available. For example, a tablet client or cell phone can remotely monitor the performance of the manufacturing cell, accessing a MES client application via cloud computing (Fig.10).
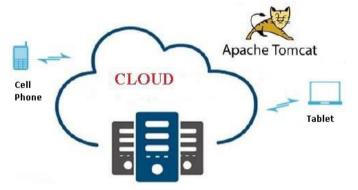

Fig. 10. Remote cloud access.

IV. RESULTS AND CONCLUSIONS

This work proposed an architecture that improves the data accessibility, integration and interoperability in a manufacturing didactic cell. The designed and tested architecture used a private cloud, IoT, and an architecture for PLC, SCADA and cloud computing (MES services). The results obtained on the digitalization of manufacturing a didactic cell satisfactorily demonstrate the beneficial resources of the cloud, such as data availability, alarms, HMI, life cycle management, process monitoring, resource management, scheduling and performance analysis. Therefore, this research allowed a manufacturing didactic cell that previously followed the ISA-95 model (Industry 3.0) to be modernized with technologies and trends of Industry 4.0.

REFERENCES

[1] Rymaszewska, A.; Helo P.; Gunasekaran,A. "IoT powered servitization of manufacturing – an exploratory case study". *International Journal of Production Economics*, v. 1, n. 1, p. 1-14, 2017.

[2] Delsing, J. "Local cloud Internet of things automation – technology and business model features of distributed Internet of things automation solutions. *IEEE Industrial Electronics Magazine,* vol. 11, n. 14, p. 8-21, 2017.

[3] Shahzad, A.; Musa, S.; Aborujilah, A.; Irfan, M. "A new cloud based supervisory control and data acquisition implementation to enhance the level of security using

testbed". *Journal of Computer Science*. n. 10, v. 4, p. 652-659, 2014.

[4] Schweichhart, K. "Reference Architectural Model industry 4.0 (RAMI 4.0): An Introduction". *Standardization & Reference Architecture, Plattform industry 4.0*, 2016.

[5] Xu, X. "From cloud computing to cloud manutacturing". *Robotics and Computer-Integrated Manufacturing*. n. 28, p. 75-86, 2012.

[6] Da Costa, C.; Mendes, C. R.; Osaki, R. "Internet of things in automated production". *EJERS, European Journal of Engineering Research and Science,*vol. 2, No. 10, p. 13-16, 2017.

[7] Foster, D.; White, L.; Adams, J.; Erdil, D. C.; Hyman, H.; Kurkovsky, S. A.; Sakr, M. and Stott, L. "Cloud computing: developing contemporary computer science curriculum for a cloud-first future". *Proceedings of the Proceedings Companion of the 23rd Annual ACM Conference on Innovation and Technology in Computer Science Education.*, p. 130-145, 2018.

[8] Kono, C.; Silva Jr, L. C. F. E.; Rodrigues, L. C. "Competitive Intelligence, Cloud Computing and Innovation in Small Enterprises". *11th International Conference on Information Systems and Technology Management – CONTECSI*. São Paulo, p. 680-704, 2014.

[9] Drath, R.; Horch, A. "Industry 4.0: Hit or Hype?" *IEEE Industrial Electronics Magazine,* p. 56-58, 2014.

[10] Unver, H. O. "An ISA-95-based manufacturing intelligence system in support of lean initiatives". *International Journal Advanced Manufacturing Technology* 65**,** 853–866 (2013).

[11] Church, P.; Mueller, H.; Ryan, C.; Gogouvitis, S. V. ; Goscinski, A.; and Tari, Z. "Migration of a SCADA system to IaaS clouds – a case study". *Journal of Cloud Computing: Advances, Systems and Applications*, v. 6, n. 11, p. 1-12, 2017.

[12] Colombo, A.; Bangemann, T.; Karnouskos, S., Delsing, J.; Stluka,P.; Harrison, R.; Jammes, F. ; and Lastra, J. L. "*Industrial Cloud-Based Cyber-Physical Systems - The IMC-AESOP Approach*". Springer International Publishing, 2014.

[13] Lojka, T.; Bundzel, M.; Zolotova, I. "Service-oriented Architecture and Cloud Manufacturing". *Acta Polytechnica Hungarica*, v. 13, n. 6, p. 25-44, 2016.

[14] Kapil, D.; Tyagi, P.; Kumar, S.; Tamta, V. P. "Cloud Computing*:* Overview and Research Issues". *International Conference on Green Informatics - IEEE*. p. 71-76, 2017.